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Users Guide for TI-59 Programs That Calculate the Rate of Fire Spread From Its Time to Cross a Triangular or Square Plot

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USERS GUIDE FOR TI-59 PROGRAMS THAT CALCULATE THE RATE OF FIRE SPREAD FROM ITS TIME TO CROSS A TRIANGULAR OR SQUARE PLOT

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ABSTRACT

Two TI-59 hand-held calculator programs are presented. Using the times at which a fire reaches the vertices of a triangular or square plot, the programs calculate the rate and direction of spread across the plot. The square plot is divided into four triangles and the rate and direction of spread is calculated for each. Arithmetic and vector averages and standard deviations are also calculated for the square.

ANNOTATION

Presents TI-59 programs that use fire arrival times to calculate the rate and direction of spread of a fire across a triangular or square plot.

USERS GUIDE FOR TI-59 PROGRAMS THAT CALCULATE THE RATE OF FIRE SPREAD FROM ITS TIME TO CROSS A TRIANGULAR OR SQUARE PLOT

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Formulas for calculating the rate of spread of a fire across a triangular plot were published by Simard et al. (1983).

The first program in this guide uses these formulas to calculate the rate and direction of spread across any triangular plot. This program may be appropriate for use in a wildfire where three landmarks can be sighted and the time when the fire reaches each noted. After the fire passes, the angle and distances between the landmarks can be measured.

The second program uses these formulas to calculate the rate and direction of spread across four triangular plots incorporated in a square. This program may be best suited for prescribed burns where plot markers can be positioned ahead of time.

PROGRAM #1--THE TRIANGULAR PLOT

DESCRIPTION

Given any triangle, let vertex A be the point the fire reached first (at time t_A), let vertex B be the point the fire reached second (at time t_B), and let vertex C be the point the fire reached last (at time t_C). Such a triangle can be placed on the xy-plane (fig. 1), with point A at the origin and B on the positive x-axis. Note that C can be in any one of the four quadrants.

Inputs needed are the two sides AB and AC, and the included angle A. Also necessary are the three times t_A, t_B, and t_C. The program calculates the rate of spread across the triangle and also gives the angle of spread 'θ' with respect to the positive x-axis. For program listing and documentation, see Appendix I.

USER INSTRUCTIONS

Step	Enter	Press	Display
1[1]	angle A	A	1/tan A[2]
2	side AB	B	AB
3	side AC	C	AC
4a	t_A	D	$-t_A$
b	t_B	R/S	t_B
c	t_C	R/S	t_C
5		E	rate of spread
6		R/S	angle of spread[3]
		[4]	

[1] Steps 1 through 4 may be entered in any order as long as all are done before step 5. In step 4, the three times must be entered in chronological order.

[2] If angle A equals plus or minus 90°, angle A will be displayed rather than 1/tan A.

[3] Relative to a base line between A and B.

[4] If the user wishes to see the rate of spread again after viewing the angle, pressing R/S will cause the program to return to step 5 without reexecuting the entire program. To change one or more of the inputs and rerun the program, only the steps involved need be changed before pressing E again. Changing one of the times of step 4 requires reentering all three times. The

display will remain fixed in the decimal configuration of the last output. To return to standard display, enter the sequence INV FIX.

SAMPLE RUN

Three landmarks are sighted during a wildfire and the times when the fire reaches each is noted: 2.0 minutes, 3.6 minutes, and 4.2 minutes. The three landmarks are labeled A, B, and C, respectively. The distance between A and B is 45 feet, A and C is 63 feet, and angle A measures 78°.

Step	Enter	Press	Display
1	78	A	.2125565617
2	45	B	45.
3	63	C	63.
4a	2	D	-2.
b	3.6	R/S	3.6
c	4.2	R/S	4.2
5		E	22.05
6		R/S	38.

Output from the program shows the fire spreading at 22 ft/min at an angle of 38° with respect to side AB.

PROGRAM #2--THE SQUARE PLOT

DESCRIPTION

The four corners of the square are labeled A through D (fig. 2). It does not matter which vertex is labeled A, as long as the order is counterclockwise. Angle M is the azimuth of B as viewed from A.

Inputs needed are the time when the fire reaches each corner of the square, the length of a side of the square 's', and the azimuth 'M'.

Define triangle A as that formed by ABC, triangle B by BCD, triangle C by CDA, and triangle D by DAB.

The program calculates the rate of spread 'ROS' and compass direction for each triangle and averages them to produce a rate and compass direction for the square. Standard deviations of the rate and direction of spread may also be output.

The program also calculates a vector average to test variability. Here the rate and direction of spread for each triangle is treated as a vector. The four vectors are added and the resultant vector divided by four. The vector average gives the rate of spread in the indicated direction. The closer this number is to the arithmetic average, the less variable the direction and/or rate of spread.

For program listing and documentation, see Appendix II.

Step	Enter	Press	Display
1[1]	time at point A	A	t_A
2	time at point B	B	t_B
3	time at point C	C	t_C
4	time at point D	D	t_D
5	side of square	E	s
6	azimuth M	R/S[2]	average ROS across square
7		R/S	average direction across square
8		R/S	standard deviation of ROS
9		R/S	standard deviation of direction
-		[3]	
10a[4]		A'	ROS across triangle A
b		R/S	direction across triangle A
11a		B'	ROS across triangle B
b		R/S	direction across triangle B
12a		C'	ROS across triangle C
b		R/S	direction across triangle C
13a		D'	ROS across triangle D
b		R/S	direction across triangle D
14a		E'	vector ROS across square
b		R/S	vector direction across square
-		[5]	

1/ Steps 1 through 4 may be entered in any order as long as all are done before step 5.

2/ The program makes all calculations at this point before displaying the arithmetic average rate of spread. This takes approximately 45 seconds.

3/ Pressing R/S at this point will cause a jump to step 14.

4/ Steps 10 through 14 may be executed in any order and repeated at will.

5/ Pressing R/S at this point will cause a jump to the output of step 6 without reexecuting the entire program. This may be followed by step 7, etc., if the user so wishes. The user can rerun the program with new data or restart the program from any point merely by returning to step 1. Unlike the triangular plot program, all inputs (even if they are the same as the previous run) must be reentered. The display will remain fixed in the decimal configuration of the last output. To return to standard display, enter the sequence INV FIX.

SAMPLE RUN

A square plot, with ten foot side, is laid out prior to a prescribed burn. Each corner is labeled counterclockwise, A to D, with the azimuth of side AB, equal to 135°. The fire reaches point B first at a time of 5.0 minutes, point C at 5.3 minutes, point A at 5.33 minutes, and point D at 5.54 minutes.

Step	Enter	Press	Display
1	5.33	A	5.33
2	5	B	5.
3	5.3	C	5.3
4	5.54	D	5.54
5	10	E	10.
6	135	R/S	26.34
7		R/S	357.
8		R/S	3.71
9		R/S	8.
10a		A'	22.42
b		R/S	357.
11a		B'	26.03
b		R/S	6.
12a		C'	31.36
b		R/S	356.
13a		D'	25.57
b		R/S	347.
14a		E'	26.17
b		R/S	357.

The output from this sample run is as follows:

	Rate of spread (ft/min)	Compass direction of spread (degrees)
Square		
Arithmetic	26	357
Vector	26	357
Triangle		
ABC	22	357
BCD	26	6
CDA	31	356
DAB	26	347
STANDARD DEVIATION	4	8

APPENDIX I

THE TRIANGULAR PLOT PROGRAM

```
000   76 LBL
001   11  A
002   42 STO
003   11  11
004   29 CP
005   32 X:T
006   42 STO
007   00  00
008   09  9
009   00  0
010   67  EQ
011   30 TAN
012   94 +/-
013   67  EQ
014   30 TAN
015   32 X:T
016   30 TAN
017   35 1/X
018   42 STO
019   00  00
020   76 LBL
021   30 TAN
022   91 R/S
```

Rearranging terms for computational convenience, the formula for the angle of spread ' θ ' given by Simard et al. is:

$$\theta = \tan^{-1}\left[\left(\frac{AB}{t_B - t_A}\right)\left(\frac{t_C - t_A}{AC \sin A}\right) - \left(\frac{1}{\tan A}\right)\right]$$

The program first checks to see if angle A equals 90° (step 010) or -90° (step 013). If so, then 1/tan A equals 0. A zero is stored in memory register 00 'R00' at steps 006-007 for this purpose. If angle A does not equal ±90°, then 1/tan A is calculated and stored in R00 (steps 015-019).

```
023   76 LBL
024   12  B
025   42 STO
026   12  12
027   91 R/S
028   76 LBL
029   13  C
030   42 STO
031   13  13
032   91 R/S
```

Sides AB and AC are read in with labels B and C and stored in R12 and R13 respectively.

```
033   76 LBL
034   14  D
035   94 +/-
036   42 STO
037   22  22
038   42 STO
039   23  23
040   91 R/S
041   44 SUM
042   22  22
043   91 R/S
044   44 SUM
045   23  23
046   91 R/S
047   76 LBL
048   15  E
049   43 RCL
050   13  13
051   32 X:T
052   43 RCL
053   11  11
054   37 P/R
055   55  ÷
056   43 RCL
057   23  23
058   95  =
059   42 STO
060   30  30
```

Since we need $t_B - t_A$ and $t_C - t_A$, first a negative t_A is stored in R22 and R23, then t_B is added to R22 and t_C to R23.

At this point all inputs have been entered into the calculator. Placing side AC in the t-register and angle A in the display permits taking advantage of the calculator's built-in vector feature. P/R at step 054 calculates the y-coordinate of this vector which equals AC sin A. Dividing by $t_C - t_A$ (steps 055-057) gives us the reciprocal of $(t_C - t_A)/(AC \sin A)$ which is stored in R30.

```
061   29 CP
062   43 RCL
063   22  22
064   67  EQ
065   38 SIN
066   35 1/X
067   65  ×
068   43 RCL
069   12  12
070   55  ÷
071   42 STO
072   21  21
073   43 RCL
074   30  30
075   75  -
076   43 RCL
077   00  00
078   95  =
079   22 INV
080   30 TAN
081   42 STO
082   31  31
083   39 COS
084   65  ×
085   43 RCL
086   21  21
087   95  =
088   42 STO
089   30  30
090   61 GTO
091   16 A'
```

The next section of the program evaluates $AB/(t_B - t_A)$. First, a check is made to see if $t_B = t_A$. If so, a special case exists and a jump is made to label SIN.

Otherwise, $AB/(t_B - t_A)$ is calculated. Since this is also an intermediate value of the spread rate calculation, it is stored in R21 before continuing. This value is then divided by $(AC \sin A)/(t_C - t_A)$ which has been stored in R30, and finally (1/tan A) from R00 is subtracted. Taking the arctan in steps 079-080 yields θ which is stored in R31.

The rate of spread of a fire across a triangular plot given by Simard et al. (1983) is:

$$r = \frac{AB \cos\theta}{(t_B - t_A)} \quad , t_B \neq t_A.$$

Cos θ is taken at step 083 and multiplied by $AB/(t_B - t_A)$ from R21. This is stored in R30 before jumping to label A' where the output is displayed.

```
092   76 LBL
093   38 SIN
094   09  9
095   00  0
096   42 STO
097   31  31
098   43 RCL
099   30  30
100   77  GE
101   16 A'
102   50 I×I
103   42 STO
104   30  30
105   09  9
106   00  0
107   94 +/-
108   42 STO
109   31  31
110   76 LBL
111   16 A'
112   43 RCL
113   30  30
114   58 FIX
115   02  02
116   91 R/S
117   43 RCL
118   31  31
119   58 FIX
120   00  00
121   91 R/S
122   61 GTO
123   16 A'
```

If t_B equals t_A, the fire is spreading perpendicular to the x-axis. In this case, θ equals $\pm 90°$ and the rate of spread equals $(AC \sin A)/(t_C - t_A)$.

The latter value had previously been calculated in steps 049-058 and stored in R30. A positive 90° is first stored in R31. The rate is checked at step 100 to see if it is positive. If not, its absolute value is taken at step 102 and stored in R30, and the angle -90° is stored in R31.

The output is displayed in the same units that the inputs were given in. Two decimal places are allowed for the user working in chains/hour. The user working in feet/minute should round to the nearest whole foot. The angles are output to the nearest degree. Steps 122-123 are added so that the output sequence can be repeated.

APPENDIX II

THE SQUARE PLOT PROGRAM

```
000   76 LBL
001   16 A'
002   43 RCL
003   22  22
004   58 FIX
005   02  02
006   91 R/S
007   43 RCL
008   23  23
009   58 FIX
010   00  00
011   91 R/S
012   76 LBL
013   17 B'
014   43 RCL
015   24  24
016   58 FIX
017   02  02
018   91 R/S
019   43 RCL
020   25  25
021   58 FIX
022   00  00
023   91 R/S
024   76 LBL
025   18 C'
026   43 RCL
027   26  26
028   58 FIX
029   02  02
030   91 R/S
031   43 RCL
032   27  27
033   58 FIX
034   00  00
035   91 R/S
036   76 LBL
037   19 D'
038   43 RCL
039   28  28
040   58 FIX
041   02  02
042   91 R/S
043   43 RCL
044   29  29
045   58 FIX
046   00  00
047   91 R/S
```

The first part of the program is actually used last. Since the program pointer always starts at location 000 when searching for a label, all user-defined labels are found within the first 100 steps. In order to further reduce execution time, absolute addressing is used rather than labels for all branching operations.

The code at left outputs the final results. The rates of spread for triangles A through D are stored in even numbered registers 22 through 28 and are output to two decimal places to satisfy users working in chains/hour. Users working in feet/minute should round to the nearest foot. The angles are stored in odd numbered registers 23 to 29 and are output to the nearest degree.

```
048   76 LBL
049   10 E'
050   43 RCL
051   30  30
052   58 FIX
053   02  02
054   91 R/S
055   43 RCL
056   31  31
057   58 FIX
058   00  00
059   91 R/S
060   61 GTO
061   04  04
062   57  57
063   76 LBL
064   11  A
065   42 STO
066   01  01
067   42 STO
068   05  05
069   42 STO
070   12  12
071   91 R/S
072   76 LBL
073   12  B
074   42 STO
075   02  02
076   42 STO
077   09  09
078   42 STO
079   10  10
080   91 R/S
081   76 LBL
082   13  C
083   42 STO
084   06  06
085   42 STO
086   07  07
087   42 STO
088   11  11
089   91 R/S
090   76 LBL
091   14  D
092   42 STO
093   03  03
094   42 STO
095   04  04
096   42 STO
097   08  08
098   91 R/S
```

R30 and R31 contain the vector averages for the rate and direction. Steps 060-062 show a jump to location 457 where the mean and standard deviation for both the rate and direction of spread are output.

The input labels come next. As each time is entered, it is stored in three different registers because each corner of the square is associated with three different triangles.

The program pages through the registers in reverse order starting with R12. R12, R11, and R10 contain times for points A, C, and B, respectively, indicating that triangle A is processed first.

R09, R08, and R07, containing times for triangle B, are processed next. Triangle C is third followed by triangle D.

```
099   76 LBL
100   15  E
101   42 STO
102   13  13
103   91 R/S
104   42 STO
105   14  14
106   02  2
107   02  2
108   42 STO
109   15  15
110   01  1
111   02  2
112   42 STO
113   00  00
114   00  0
115   42 STO
116   30  30
117   42 STO
118   31  31
119   42 STO
120   32  32
121   42 STO
122   33  33
```

Label E stores the length of one side of the square in R13, and the azimuth in R14.

R15 is used for indirect addressing. Whenever a rate of spread or a direction is calculated, R15 contains the address where it should be stored. It is originally set to 22.

R00 is also used for indirect addressing. It is originally set at 12 and is intended to input the correct triangle to the program as noted above. R30 to R33 are cleared for later summations.

The main loop of the program (steps 123-352) is executed four times, once for each triangle. Since the process is the same on each, for clarity this discussion will use the notation of the first triangle. As noted above, the times for the first triangle are brought into the loop in the order t_A, t_C, t_B. The notation $\min(t_A,t_C)$ is used to indicate the lesser of t_A and t_C while $\max(t_A,t_C)$ is used to indicate the greater of the two.

The general formula for the angle of spread 'θ' across a right isosceles triangle (Simard et al. 1983) is:

$$\theta = \tan^{-1}\left[\alpha\left(\frac{t_3 - t_1}{t_2 - t_1}\right) - \beta\right]$$ where t_1, t_2 and t_3 are the three times in chronological order, and α and β are constants dependent on the specific case involved (fig. 3).

Each case can have a subcase by rotating the triangle 180°. To differentiate between the two, the first group is called 'a' and the rotated group 'b'. Steps 123-188 identify the particular case and subcase as well as place $(t_3 - t_1)$ in R19 and $(t_2 - t_1)$ in R20.

```
123  86 STF
124  01  01
125  01  1
126  42 STO
127  17  17
128  42 STO
129  18  18
130  73 RC*
131  00  00
132  32 X:T
133  01  1
134  94 +/-
135  44 SUM
136  00  00
137  73 RC*
138  00  00
139  42 STO
140  19  19
141  77  GE
142  01  01
143  50  50
144  32 X:T
145  42 STO
146  19  19
147  22 INV
148  86 STF
149  01  01
150  01  1
151  94 +/-
152  44 SUM
153  00  00
154  73 RC*
155  00  00
156  42 STO
157  20  20
158  77  GE
159  01  01
160  70  70
161  00  0
162  42 STO
163  17  17
164  32 X:T
165  48 EXC
166  20  20
167  61 GTO
168  01  01
169  84  84
```

The sequence begins by setting flag 1, which is used to separate case a from b. A one is then stored in R17 and R18 indicating β and α respectively.

Next t_A is recalled (steps 130-131) and entered into the t-register. RC* at step 130 does not appear on the calculator's keyboard. It is achieved by entering the sequence RCL IND.

The program then recalls t_C (steps 133-138), stores it in R19, and tests it against t_A (step 141). If t_C is less than t_A, their locations (t-register and R19) are switched (steps 144-146) and flag 1 is reset (steps 147-149) indicating case 1b, 2a, or 3a.

Then t_B is recalled (steps 150-155) and stored in R20. If it is less than the time currently in the t-register, $\min(t_A,t_C)$, then the triangle is case 3 and β (R17) is set equal to zero (steps 161-163), $\min(t_A,t_C)$ is moved to R20, and t_B is placed in the display (steps 164-166) before jumping to step 184.

```
170   32 X:T
171   48 EXC
172   19  19
173   77  GE
174   01  01
175   82  82
176   42 STO
177   20  20
178   02  2
179   42 STO
180   18  18
181   32 X:T
182   48 EXC
183   19  19
184   94 +/-
185   44 SUM
186   19  19
187   44 SUM
188   20  20
```

If, on the other hand, t_B is greater than $\min(t_A,t_C)$ then it passes the test at step 158 causing a jump to step 170. The program moves t_B to the t-register, $\min(t_A,t_C)$ to R19, and $\max(t_A,t_C)$ to the display (steps 170-172).

A test is made at step 173 and if $\max(t_A,t_C)$ is greater than t_B, the triangle is case 1, and a jump is made to step 182.

If $\max(t_A,t_C)$ is less than t_B, the triangle is case 2, $\max(t_A,t_C)$ is placed in R20, α (R18) is set equal to two, and t_B is moved to the display (steps 176-181).

Both case 1 and case 2 execute steps 182-183 and succeed in placing the maximum time, t_3, in R19 and the minimum time, t_1, in the display. All three cases come together at step 184 where t_1 is made negative and added to t_3 in R19 and t_2 in R20 (steps 185-188).

```
189   29 CP
190   43 RCL
191   20  20
192   67  EQ
193   02  02
194   22  22
195   43 RCL
196   18  18
197   65  ×
198   43 RCL
199   19  19
200   55  ÷
201   43 RCL
202   20  20
203   75  -
204   43 RCL
205   17  17
206   95  =
207   22 INV
208   30 TAN
209   42 STO
210   21  21
211   39 COS
212   65  ×
213   43 RCL
214   13  13
215   55  ÷
216   43 RCL
217   20  20
218   65  ×
219   61 GTO
220   02  02
221   32  32
```

The program now calculates θ. If $t_2 = t_1$, $\theta = 90°$. This special case is processed with a test at step 192 and a jump to 222 where 90° is stored as the angle. All other cases are handled with steps 195-210.

The formula for the rate of spread (Simard et al. 1983) is:

$$ROS = \frac{s \cos\theta\sqrt{\alpha}}{(t_2 - t_1)}$$

where s is the length of a side of the square. ROS is calculated in steps 211-221 and 232-235.

```
222   09   9
223   00   0
224   42 STO
225   21   21
226   43 RCL
227   13   13
228   55   ÷
229   43 RCL
230   19   19
231   55   ÷
232   43 RCL
233   18   18
234   34 √x
235   95   =
236   72 ST*
237   15   15
238   42 STO
239   34   34
240   44 SUM
241   32   32
242   33 x²
243   44 SUM
244   33   33
245   01   1
246   44 SUM
247   15   15
```

If we are dealing with the special case where t_2 equals t_1, the formula simplifies to:

$$ROS = \frac{s}{(t_3 - t_1)\sqrt{\alpha}}$$

which is calculated in steps 226-235.

ROS is stored indirectly in the register indicated by R15. ST* at step 236 does not appear on the calculator's keyboard. It is achieved by entering the sequence STO IND. ROS is also stored in R34 for later vector calculations and summed in R32 with its square summed in R33 for later standard deviation calculations.

θ is stored in R21 for subsequent azimuth calculations.

```
248   32 X:T
249   43 RCL
250   17   17
251   67   EQ
252   02   02
253   72   72
254   87 IFF
255   01   01
256   02   02
257   65   65
258   09   9
259   00   0
260   94 +/-
261   75   -
262   61 GTO
263   03   03
264   07   07
265   01   1
266   08   8
267   00   0
268   85   +
269   61 GTO
270   03   03
271   07   07
272   43 RCL
273   18   18
274   67   EQ
275   02   02
276   95   95
277   87 IFF
278   01   01
279   02   02
280   88   88
281   01   1
282   03   3
283   05   5
284   75   -
285   61 GTO
286   03   03
287   07   07
288   04   4
289   05   5
290   94 +/-
291   85   +
292   61 GTO
293   03   03
294   07   07
```

The general formula for finding the compass direction of spread 'DOS' is: DOS = $N \pm \theta + M$ where $N \pm \theta$ is dependent on the case involved. Steps 248-306 begin the calculation with 'N +' or 'N -', followed by a jump to 307 for '$\theta + M$'.

Cases 1 and 2 pass the test at step 251 and jump to 272. Steps 258-264 are for case 3a and 265-271 for case 3b.

Case 3a: DOS = $-90° - \theta + M$

Case 3b: DOS = $180° + \theta + M$

Cases 1 and 2 are tested again at step 274. Case 1 passes and jumps to 295. Case 2a is handled in steps 281-287 and case 2b in steps 288-294.

Case 2a: DOS = $135° - \theta + M$

Case 2b: DOS = $-45° + \theta + M$

```
295   87  IFF
296   01   01
297   03   03
298   05   05
299   09   9
300   00   0
301   85   +
302   61  GTO
303   03   03
304   07   07
305   00   0
306   75   -
307   43  RCL
308   21   21
309   85   +
310   43  RCL
311   14   14
312   95   =
313   32  X:T
314   43  RCL
315   34   34
316   32  X:T
317   37  P/R
318   44  SUM
319   30   30
320   32  X:T
321   44  SUM
322   31   31
323   32  X:T
324   22  INV
325   37  P/R
326   32  X:T
327   93   .
328   05   5
329   94  +/-
330   32  X:T
331   77  GE
332   03   03
333   39   39
334   85   +
335   03   3
336   06   6
337   00   0
338   95   =
```

Case 1b is processed in steps 299-304 and case 1a in 305-306.

Case 1b: DOS = 90° + θ + M

Case 1a: DOS = 0° - θ + M

All cases come to step 307 where θ is either added to or subtracted from the previous calculation and added to the original azimuth 'M'.

Steps 313 to 322 change polar to rectangular coordinates. The y-values are summed in R30 and the x-values in R31.

Steps 323-325 return the angle to polar within the field $-90° \leq DOS < 270°$.

Angles which are negative have 360° added to them in steps 326-338.

```
339   72 ST*
340   15  15
341   01  1
342   44 SUM
343   15  15
344   09  9
345   00  0
346   94 +/-
347   44 SUM
348   14  14
349   97 DSZ
350   00  00
351   01  01
352   23  23
353   43 RCL
354   31  31
355   55  ÷
356   04  4
357   95  =
358   32 X↕T
359   43 RCL
360   30  30
361   55  ÷
362   04  4
363   95  =
364   22 INV
365   37 P/R
366   32 X↕T
367   42 STO
368   30  30
369   93  .
370   05  5
371   94 +/-
372   32 X↕T
373   77  GE
374   03  03
375   81  81
376   85  +
377   03  3
378   06  6
379   00  0
380   95  =
381   42 STO
382   31  31
```

The angle is stored indirectly to the location address that is stored in R15.

Because triangle B is rotated 90° from triangle A, and C is rotated 90° from B, etc., 90° is subtracted from the azimuth 'M' at this point before returning to the beginning of the main loop at step 123.

Finally, after the main loop is executed four times, once for each triangle, the program arrives at step 353.

The vector averages are calculated in steps 353-382 with the rate of spread stored in R30 and the angle of spread, after converting to positive degrees, stored in R31.

```
383  75  -
384  01  1
385  08  8
386  00  0
387  95  =
388  42  STO
389  11  11
390  85  +
391  03  3
392  06  6
393  00  0
394  95  =
395  42  STO
396  12  12
397  04  4
398  42  STO
399  00  00
400  42  STO
401  03  03
402  00  0
403  42  STO
404  04  04
405  42  STO
406  05  05
```

A problem may arise when calculating standard deviations, if the angles are close to 0°. For example, 355° and 0° are only 5° apart yet their magnitudes are 355° apart. To avoid this problem, 180° is subtracted from the vector average for a lower bound and stored in R11. 180° is added to the vector average as an upper bound and stored in R12.

After preparing R00 to R05 for statistics calculations, each angle is checked to see if they lie within the bounds.

```
407   02   2
408   03   3
409   42 STO
410   15   15
411   43 RCL
412   11   11
413   32 X↕T
414   73 RC*
415   15   15
416   77   GE
417   04   04
418   24   24
419   85   +
420   03   3
421   06   6
422   00   0
423   95   =
424   32 X↕T
425   43 RCL
426   12   12
427   32 X↕T
428   22 INV
429   77   GE
430   04   04
431   37   37
432   75   -
433   03   3
434   06   6
435   00   0
436   95   =
437   44 SUM
438   04   04
439   33 X²
440   44 SUM
441   05   05
442   02   2
443   44 SUM
444   15   15
445   97 DSZ
446   00   00
447   04   04
448   11   11
```

If outside the bounds, 360° is either added to or subtracted from the angle before summing. However, the original angle stored in registers 23 to 29, remains unchanged.

Each of the four angles of spread ±360°, are summed in R04 and their squares summed in R05.

```
449   43 RCL
450   32  32
451   42 STO
452   01  01
453   43 RCL
454   33  33
455   42 STO
456   02  02
457   79  x̄
458   58 FIX
459   02  02
460   91 R/S
461   32 X↕T
462   58 FIX
463   00  00
464   91 R/S
465   22 INV
466   79  x̄
467   58 FIX
468   02  02
469   91 R/S
470   32 X↕T
471   58 FIX
472   00  00
473   91 R/S
474   61 GTO
475   10 E'
```

Each of the four rates of spread and their squares previously summed in steps 240-244 are now entered into R01 and R02.

Using the calculator's build-in functions for calculating the mean and standard deviation, each can be displayed by repeatedly pressing the R/S key. First is the mean of the rates, then the mean of the directions, then the standard deviation of the rates and finally the standard deviation of the directions.

Pressing R/S once more causes a jump to label E' where the vector averages are output. Although pressing label E' accomplishes the same thing, this feature was added to eliminate one keystroke for user convenience.

LITERATURE CITED

Simard, A. J., J. E. Eenigenburg, K. B. Adams, R. L. Nissen, and A. G. Deacon. 1982. A General Procedure for Sampling and Analyzing Wildland Fire Spread. Forest Science (in press).

FIGURE LEGEND

Figure 1.--The triangular plot.

Figure 2.--The square plot.

Figure 3.--The three right isosceles triangles.

Figure 1.

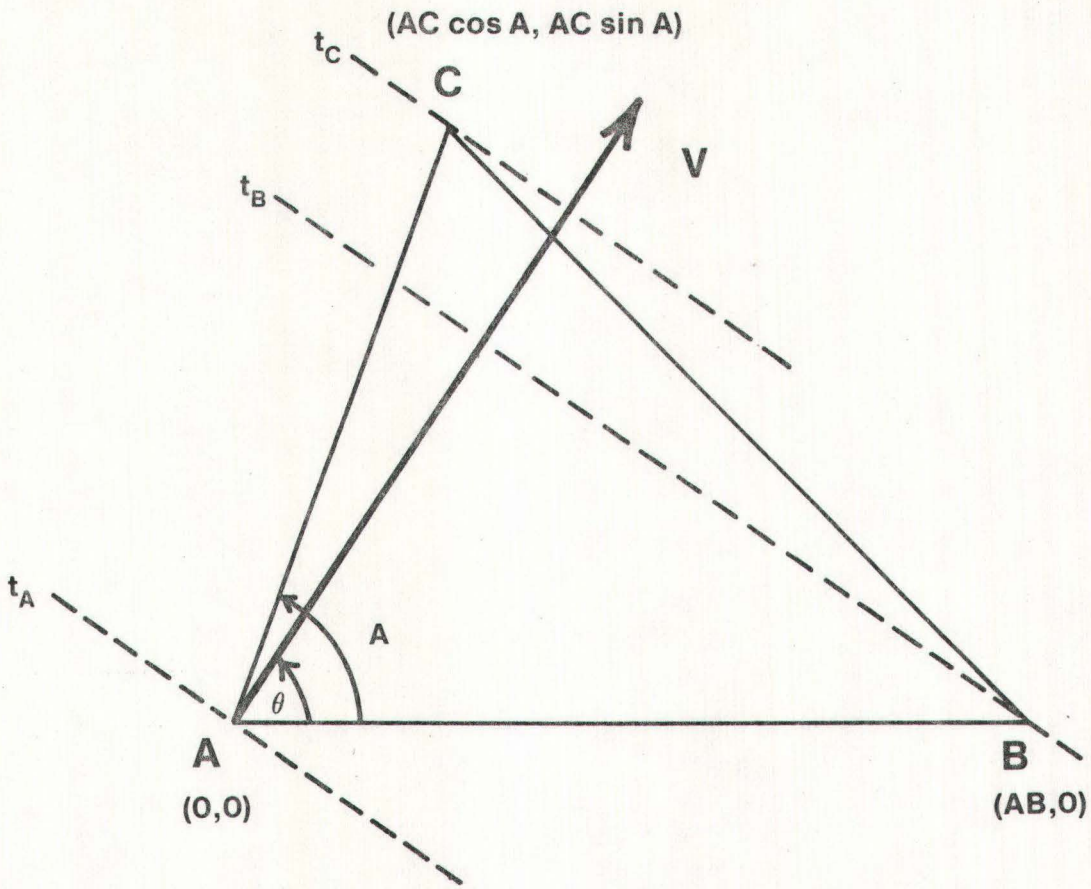


Figure 2.

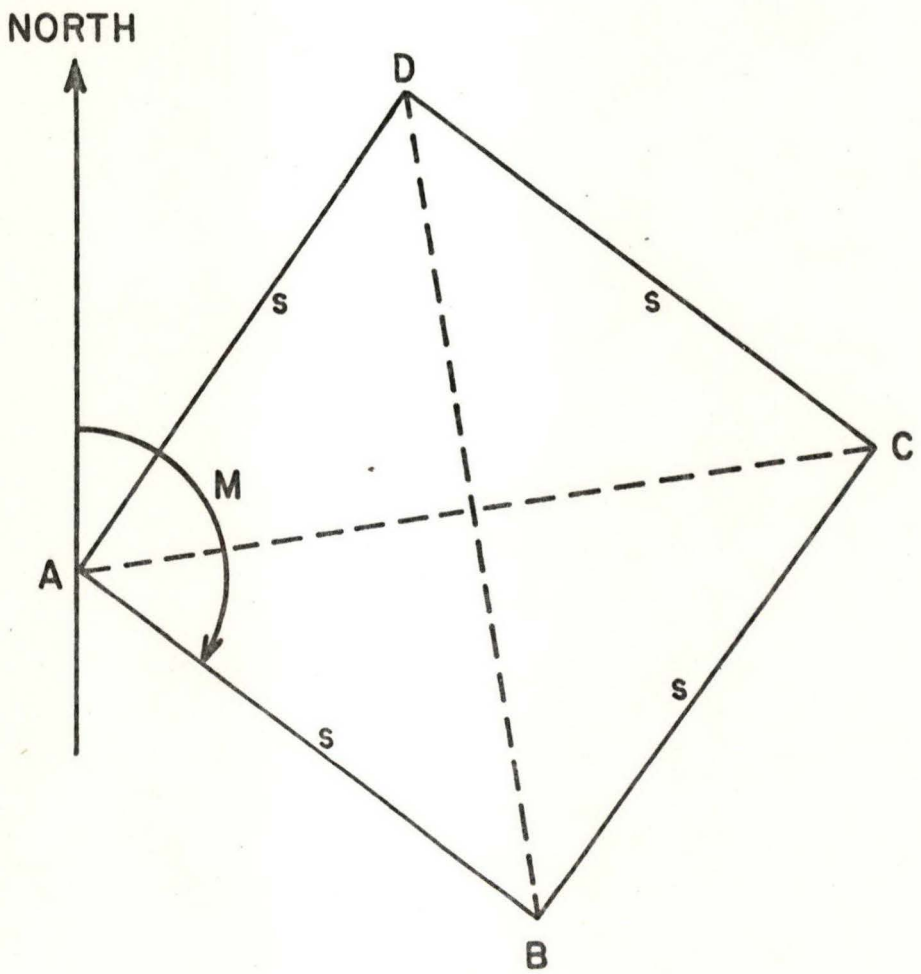
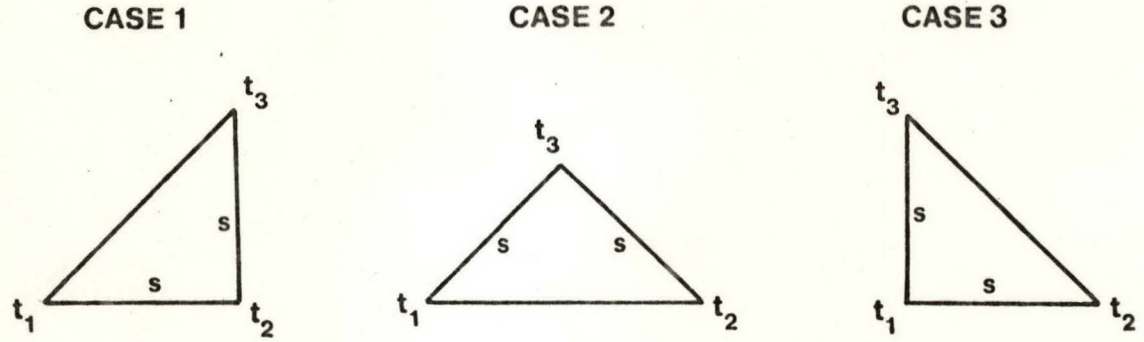


Figure 3.



α:	1	2	1
β:	1	1	0